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RF Vacuum Microelectronics

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13. ABSTRACT (Maximum 200 words)

We summarize our progress towards developing a thin film edge emitter vacuum transistor capable of 1 GHz modulation. Design of the thin film edge emitter vacuum transistors was completed this quarter. The first fabrication run of these devices is presently in progress. In addition, two high frequency probes for a wafer testing of the vacuum transistors were characterized.

14. SUBJECT TERMS
Vacuum microelectronics, edge emitter, thin film technology, triodes

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R&D Status Report
RF Vacuum Microelectronics
Quarterly Progress Report #7
(4/1/93 - 6/30/93)

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Effective Date of Contract:	September 30, 1991
Contract Expiration Date:	May 31, 1993 (Baseline)
Option Expiration Date:	November 30, 1993
Contract Amount: Baseline	$1,315,650
Option:	$ 465,000

Principal Investigator:	Tayo Akinwande 612/887-4481
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Title of Work: **RF Vacuum Microelectronics**

I. Executive Summary

Technical Approach: Our technical approach is to utilize thin film technology and surface micromachining techniques to demonstrate an edge emitter based vacuum triode. An array of vacuum transitors are connected in parallel to achieve microwave performance. The edge emitter triode approach offers several potential advantages to achieving high frequency device operation (compared to cone emitters or wedge emitters):

- Thin film processes for the films used in the triode process are well controlled and reproducible. Control of film thicknesses to within 5% for the emitter film thickness is easily attainable resulting in a well-controlled edge emitter.
- Device capacitance for the edge emitter is less than that achievable for cones or wedges resulting in potentially higher frequency operation.
- The fabrication process is a planar process, compatible with most silicon IC manufacturing.

Program Objective: **Demonstrate an edge emitter based microwave vacuum transistor with gain at 1 GHz continuously for 1 hour.**

Key Achievements (this reporting period)

- Completed the design of a thin-film-edge emitter microwave vacuum transistor.
- Completed the design, assembly and characterization of two prototypes of the vacuum feedthrough high frequency probes that will allow on wafer testing and characterization of microwave vacuum transitors.

II. Milestone Status

	Completion Date		
	Planned	Actual	Comments
Task 1. Field Emitter Development			
Test Structure Design Complete		1/91	complete
Determine Workable Emitter Structure		12/92	complete
Demonstrate Emission Current of 10 μA/μm	11/92	11/92	complete
Deliver 10 Field Emitting Diodes	12/92	10/92	delivered
Task 2. Process Development			
High Resistivity Thin Film Resistor	4/92	9/92	complete
Complete Dielectric Studies	5/92	6/92	complete
Mechanical and Electrical FEM Analysis	5/92	8/92	complete
Task 3. Triode Development			
Triode Design Complete	4/92	5/92	complete
Demonstrate Reliable/Uniform Current Emission	7/92	10/92	complete
Demonstrate Modulated/Edge Emitter Triode	8/92	12/92	complete
Demonstrate 1 GHz Modulation of Triode	2/93	12/92	behind plan
Deliver 2 Triodes	3/93	8/93	behind plan
Task 4. Final Report (Baseline)	4/93	4/93	behind plan
Task 5. High Frequency Demo			
Design Microwave Vacuum Transistor	6/93	6/93	complete
Complete Process Development	6/93	6/93	complete
Complete High Frequency Probe Assembly	6/93	6/03	complete
Demonstrate Vacuum Transistor with High Current	10/93	10/93	on plan
Demonstrate 1 GHz Modulation with Gain	10/93	10/93	on plan

III. Technical Progress

Efforts during this reporting period focused on fabrication and testing of the thin film edge emitter vacuum transistors.

Task 1. Field Emitter Development

This task was completed at the end of the fourth quarter.

Task 2 Process Development

This task was completed at the end of the fourth quarter.

Task 3 Triode Development

This task was completed at the end of the sixth quarter with the demonstration of the vacuum transistor.

Task 4 High Frequency Triode Development

Our efforts in this quarter focused on:

- Microwave vacuum transistor design.
- Development of a vacuum feedthrough with high frequency probes for microwave measurements.

Microwave Vacuum Transistor Design

We designed vacuum transistors that can be probed on wafer through vacuum feedthroughs. The microwave vacuum transistor consists of an array of thin-film-edge emitter vacuum transistors that were demonstrated earlier in the program. The vacuum transistor building blocks have emitter esdge widths of 3 μm to 200 μm. In order to reduce the device impedance and also to have sufficient gain, the microwave vacuum transistor is designed to have a nominal emitter current of 20 - 24 mA. Based on our earlier results of emission currents of 10 μA/μm of edge width, the microwave vacuum transistors have thin-film-edge emitters that are approximately 24 μm long. The emitter cell width varies from 3 μm to 200 μm. These are grouped into 200 μm long segments, and twelve 200 μm long segments make a device. The cells and segments are interconnected by existing metal lines in the lower control electrode (LCE), upper control electrode (UCE), the emitter, the resistor and the anode/pad metallizations.

The microwave transistor has pad metallization that makes the device probable on wafer and can be tested at frequencies up to 2 GHz. The input (gate) and output (anode) pads are both surrounded by ground planes (emitter) on either side. The arrangement is very similar to devices that are designed to be probed by cascade microprobes.

For the 2400 μm wide device, we expect a current of 20-24 mA with a transconductance of 4 ms and a capacitance 408 fF. This should result in an f_T of 158 GHz and a maximum available gain of 9.5 dB at 1 GHz. The microwave vacuum transistor design has been completed, and fabrication masks have been purchased.

We started the first fabrication run and we have now completed 50% of the fabrication steps. The first fabrication run will be completed in mid-August and we shall begin DC tests immediately.

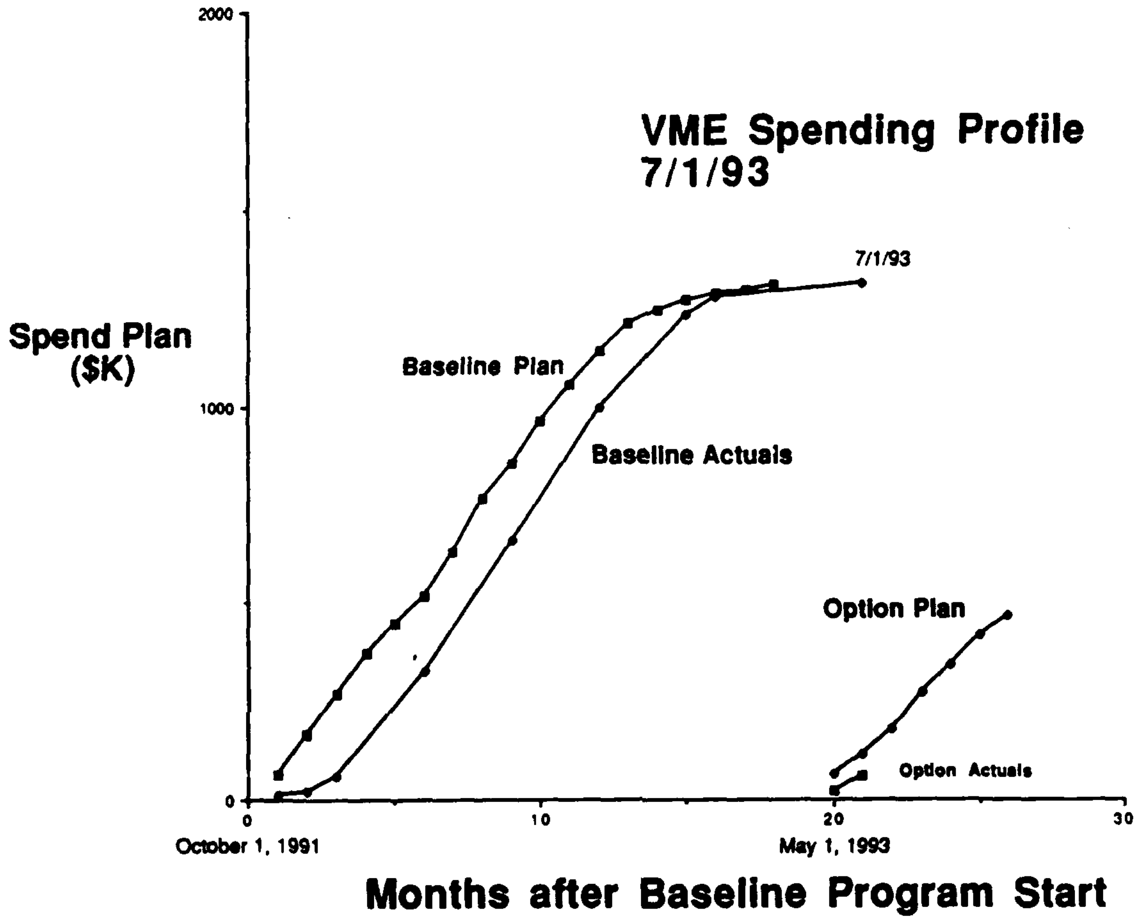
Microwave Vacuum Feedthrough Probes

We have designed new probes that will allow us to test microwave vacuum transistor at the wafer level. We have assembled two sets of probes.

The first set of probes used conventional vacuum feedthroughs in which the BNC connectors are grounded to the flange. The BNC connectors are fed by rigid coaxial cables to the device probes. The device probes are mounted on a 50Ω printed circuit board with a ground plane. The ground plane is connected to the emitter probe as well as the shields of the gate (input) and anode (output) coaxial cables. The insertion loss is less than 5 dB at 1 GHz which is excellent, however the probe isolation is only about 20 dB. This implies that any device that does not have at least -20 dB gain between the input and output could not be characterized. Our analysis is that the isolation between input and output is poor because the outer shield of the BNC connectors is grounded to the flange creating multiple grounds for the device under test and signal feedthrough between input and output. The low insertion loss indicates that input signals reach the probe tip without much degradation.

We ordered a new flange with two BNC connectors that have isolated shields. We constructed a similar probe to that described above. The degradation above 1 GHz is due to the use of another connector between the BNC and the rigid coaxial cable. An isolation of better than 40 dB at 1 GHz was measured showing an improvement of 20 dB over the first probe prototype. The results indicate that we should be able to feed signals to the device at 1 GHz without much signal degradation and measure the output signal without much interference from the feedthrough signals.

IV. Fiscal Status



	Baseline Program	Option Phase
Expenditures this quarter	$ 87K	$ 58K
Total expenditures to date	$1,395K	58K
Projected expenditures (baseline):		
7/93 - 9/93	0	267K
10/93 - Program Completion	0	140K
Total Projected Cost for Program	$1,315,650*	$465K

*Total cost to ARPA. The remaining funding for the baseline program (~$80K) is being cost-shared by Honeywell through a limitation of its overhead rates. In addition, as a result of the February 1, 1993 program review with ARPA, Honeywell agreed to an additional investment (internal development funds) of approximately $71K to provide further testing, testing enhancements and process enhancements to the VME effort. Of this $71K committed all has been spent.

The present probe assembly should allow us to test wafers in vacuum to a frequency of about 2 GHz. We are in the process of designing a third probe with isolated SMA connectors which should extend our testing capability to 8-10 GHz. Details of these technical results can be found in the Quarterly Technical Report for 4/1/93 - 6/30/93.

Plans for Next Reporting Period

- Complete fabrication of first VME processing run using the redesigned VME transistors described above.
- Complete DC characterization of VME devices fabricated in first run.
- Begin initial high frequency characterization of first run VME devices.
- Initiate second fabrication run of VME devices.

V. Programmatics

- A review of program status was given at the VME Tri Services Review in Washington, Dc at the end of June.
- Our paper entitled "Monolithic Lateral Thin-Film-Edge Emitter Vacuum Transistor" was accepted at the IVMC at Newport, Rhode Island Conference held mid-July 1993.
- Program progress was reviewed with Dr. Bob Parker and Dr. Henry Gray on May 4, 1993 at NRL.